PRECISE OBSERVATIONS OF LUNI-SOLAR AND FREE CORE NUTATION

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Abstract. The previous analysis of McCarthy and Luzum (1991b) is repeated using an additional three years of VLBI observations. A new set of empirical corrections to the 1980 IAU Nutation Theory is determined and compared to current geophysical models.

1. INTRODUCTION

The shortcomings of the 1980 IAU Nutation Theory (Seidelmann 1982) as recommended by the International Earth Rotation Service (IERS) Standards (McCarthy 1992) have been documented for some time (see McCarthy and Luzum 1991b for further details). It has become standard practice to estimate corrections for the nutation angles $\Delta\psi$ (longitude) and $\Delta\epsilon$ (obliquity) when analyzing Very Long Baseline Interferometry (VLBI) and Lunar Laser Ranging (LLR) observations.

The IERS Central Bureau and the National Earth Orientation Service (NEOS), acting as the IERS Sub-bureau for Rapid Service and Predictions, publish the observed corrections $d\Delta\psi$ and $d\Delta\epsilon$ and their predictions. With the addition of new VLBI and LLR data, and the increased accuracy of the observations, it is appropriate to revisit the earlier analysis to determine improved estimates of corrections to the IAU nutation model.

2. NUTATION OBSERVATIONS

The observations of $d\Delta\psi$ and $d\Delta\epsilon$ used in this analysis were taken from the combination solution of the IERS Sub-bureau for Rapid Service and Prediction (McCarthy and Luzum 1991a). The NEOS series extends from

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MJD 44509 (1980 September 27) to MJD 49259 (1993 September 29). Corrections to the larger terms of the IAU nutation model are also provided by the Jet Propulsion Laboratory (JPL) from the analysis of observations using the Deep Space Network (DSN) data.

Data from both the Time and Earth Motion Precision Observations (TEMPO) and the Catalog Maintenance and Enhancement (CAT M&E) projects have been used to form estimates of the corrections to a standard nutation model (Steppe et al. 1994). Besides corrections to the nutation coefficients determined from VLBI, additional estimates can be derived from lunar laser ranging (LLR) observations (Williams et al. 1991; Whipple 1993).

Again, coefficients are not calculated for every term, but corrections for the larger ones have been computed.

3. COMPUTATION PROCEDURE

The first step in obtaining a nutation model was to adopt the Souchay et al. (1994) model as a reference. This model is based on the solid Earth model of Kinoshita and Souchay (1990) modified for the non-rigid Earth using the procedure of Wahr (1981). The differences between the Souchay and ZMOA-1990-2 (Herring et al. 1991) models were computed for each term in the Souchay series.

The largest differences were interpreted as indications of disagreements between the theories and were selected as prime candidates for numerical solutions using the observations. Some of the terms chosen can be highly correlated with other terms in the solution. When this occurred, the terms with the largest expected amplitudes were included in the solution while the smaller amplitude terms were excluded.

A simultaneous, weighted least-squares solution was made to determine the corrections to the selected terms of the nutation series using the NEOS combination data. The weights used in the solution were inversely proportional to the square of the errors associated with each point in the time series of observations.

4. FREE CORE NUTATION

The amplitude spectra show no significant terms remaining in the corrected series. The spectra of the observed time series near the expected FCN were further investigated by restoring those corrections having periods near the FCN, namely the 386- and 411- day terms. Power spectra computed using the Maximum Entropy Method (MEM or Burg's Method) (Kay 1988) show that the apparent FCN decreases in amplitude with time and changes in period.

Using Fourier analyses, the "FCN" in the combination nutation series can be adequately described using two terms in $\Delta\psi$ and one term in $\Delta\epsilon$. The terms in $\Delta\psi$ have periods of 419 and 465 days. The period of the term in $\Delta\epsilon$ is 414 days.

Due to the uncertain nature of the observed FCN, no FCN model is adopted in this work. The reason for this is that the observations seem to show multiple periodicities that are not explained by current theories, raising the question of whether the phenomenon being observed is really free core nutation. Also the amplitude of the "FCN" appears to decay over time to the point where, in recent times, the peak is barely above the noise level.

5. DISCUSSION

The precision of the coefficients is roughly 0.01 to 0.03 *mas* (millisecond of arc). There are significant unexplained differences between the nutation coefficients derived from the NEOS combined solution based on VLBI observations and those derived from LLR (Williams et al. 1991; Whipple 1993), and from optical observations (Vondrak 1993).

Comparison of the corrections derived here with the LLR and optical values indicates that the accuracy may be larger by a factor of at least ten. The solution of Whipple (1993) does not solve for a correction to the 9.3-year term, and we find that variations in this term cause significant changes in the estimates of precession and the 18.6-year term. This may be the cause of the discrepancies between the solutions.

On the other hand, the current analysis compares favorably with the nutation coefficients derived using JPL VLBI. The rms of the residuals between the nutation correction coefficients for the NEOS and JPL models is 0.6 *mas* in $d\Delta\psi$ and 0.3 *mas* in $d\Delta\epsilon$. The rms of the observational residuals for dates after MJD 45700 (the date when routine IRIS VLBI observations began) is 0.492 *mas* in $d\Delta\psi \sin\epsilon_0$ and 0.496 *mas* in $d\Delta\epsilon$.

In considering the adoption of changes in the IAU model for nutation, it is important to recall that changes must also be made in the precession constant. Introduction of changes in nutation without corresponding changes in precession will not improve the agreement between observations and theory. An empirical model such as that presented here could be used for special applications, including modeling a priori estimates of $d\Delta\psi$ and $d\Delta\epsilon$ for precise astrogeodetic data reduction.

6. CONCLUSION

Analysis of VLBI and LLR observations of celestial pole offsets are in good agreement with the conclusion that corrections to the IAU 1980 Nutation

Theory are required to meet high-precision requirements. Comparisons of solutions show that some differences still exist among various analyses but that agreement is now at the level of 0.5 *mas*.

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